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Control and Energy Monitoring Scheme for a Stand-Alone Wind Energy Conversion System

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Abstract - Present energy need heavily relies on the conventional sources. But the limited availability and steady increase in the price of conventional sources has shifted the focus toward renewable sources of energy. Among the available alternative sources of energy, wind energy is considered to be one of the proven technologies. With a competitive cost for electricity generation, wind energy conversion system (WECS) is nowadays deployed for meeting both grid-connected and stand-alone load demands.

However, wind flow by nature is intermittent. In order to ensure continuous power supply, suitable storage technology is used as backup. A storage system such as a battery bank may be used. In this thesis, the sustainability of a hybrid wind energy and battery system is investigated for meeting the requirements of a stand-alone dc load. A charge controller for battery bank based on turbine maximum power point tracking and battery state of charge is developed to ensure controlled charging and discharging of battery. The mechanical safety of the wind energy conversion system is assured by means of pitch control technique. Both the control schemes are integrated and the efficiency is validated by testing it with various load and wind profiles in numerical computation software SCILAB.

The SCILAB model is intended to simulate the behavior of wind turbine using synchronous generators and control the wind electrical energy conversion processes. Rotational speed and torque become the controlled variables in wind energy and mechanical energy conversion process. Control scheme has been developed for switching DC-DC buck type converter. It is possible to predict the behaviour of the system by simulation using SCILAB-XCOS software.

I. INTRODUCTION

Wind Energy Conversion System (WECS) is one of the most versatile non-conventional resources of energy due to the ever-growing demand of electricity supply. Since wind is a natural source and its utility is based on the climatic variation, it is essential to tap this energy effectively for meeting the demand [1]. Due to the development of technology in the synchronous and asynchronous generators, it is possible to effectively employ these generators in WECS. The wind energy can be used for stand-alone load or connected to grid.

Nowadays, many stand-alone loads are powered by renewable energy [2][3]. With this interest on using wind energy technology for a stand-alone application, a great deal of research is being carried out for selecting a suitable generator for stand-alone WECS.

For optimizing the use of wind energy to a stand-alone or grid connected system, proper control strategy and energy monitoring scheme have to be developed. Since wind energy is intermittent, a hybrid system such as wind-battery system may be employed for effective utilization of wind energy.

Charge controller for battery bank based on turbine maximum power point tracking (MPPT) and battery state of charge is developed to ensure controlled charging and discharging of battery. Mechanical safety of WECS is assured by proposed pitch control technique. MPPT logic is used to operate at optimum tip–speed ratio (TSR).

II. MODELLING

A. Wind Model

The wind models describe the fluctuations in the wind speed, which influences the power quality and control characteristics of the wind farm. Thus, the wind speed model simulates the wind speed fluctuations that influence the fluctuations in the power of the wind turbines. The wind acting on the rotor plane of a wind turbine is very complex and includes both deterministic effects (mean wind, tower shadow) and stochastic variations due to turbulence.

1.1. AERODYNAMIC MODEL

A wind turbine is essentially a machine that converts the kinetic energy of the moving air (wind) into mechanical energy at the turbine shaft and finally into electrical energy. The interaction of the turbine with the wind is complex but a reasonably simple representation is possible by modeling the aerodynamic torque or the aerodynamic power as described below. The force of the wind creates aerodynamic lift and drag forces on the rotor blades, which in turn produce the torque on the wind turbine rotor.

The aerodynamic torque is given by,

$$T_r = \frac{P_{aero}}{w_{rotor}} = \frac{\frac{1}{2}\left(\rho\pi R^2 \left(v_{eq}\right)^3 C_p(\lambda, \theta_{pitch})\right)}{(\lambda)(\frac{v_{eq}}{R})}$$

Where P_{aero} is the aerodynamic power developed on the main shaft of a wind turbine with radius R at a wind speed $\boldsymbol{v_{eq}}$ and air density $\boldsymbol{\rho}$. It is expressed by

$$\boldsymbol{P_{aero} = 0.5 * \rho\pi R^2 v_{eq}{}^3 c_p\left(\lambda, \theta_{pitch}\right)}$$

$\boldsymbol{w_{rot} = \lambda * \frac{v_{eq}}{R}}$ is the rotor speed.

The air density $\boldsymbol{\rho}$ is dependent on the temperature and pressure of the air.

The dimensionless power coefficient $\boldsymbol{c_p\left(\lambda, \theta_{pitch}\right)}$ represents the rotor efficiency of the turbine.

This coefficient depends on the tip speed ratio expressed by $\lambda = \boldsymbol{w_{rot} \cdot \frac{R}{v_{eq}}}$ and the blade angle $\boldsymbol{\theta_{pitch}}$; $\boldsymbol{w_{rot}}$ denotes the rotor speed. For a constant-speed turbine, the power coefficient decreases when the wind speed $\boldsymbol{v_{eq}}$ increases (λ small). This fact is used in the passive stall control wind turbine.

The efficiency coefficient ($\boldsymbol{c_p}$) changes with different negative values of the pitch angle (0^0, - 1^0, -2^0, -3^0) but the best efficiency is obtained for $\theta_{pitch} = 0^0$.

III. HYBRID WIND-BATTERY SYSTEM

Aero dynamic model is used to design this hybrid wind and battery system. Turbine speed and wind speed are the inputs for the transmission system which is connected to shaft of wind generator. Depending on these speed, AC output is generated. This generated output is rectified by rectifier to produce suitable DC output, which is then fed to a DC-DC buck converter. Output of the converter is then fed to battery bank. In battery bank, there is a provision made for monitoring the state of charge (SOC). By employing MPPT logic, region of maximum power is tracked from battery bank and fed to charge controller. Based on power point level and state of charge, the necessary pulse width is generated by PWM control. Output of charge controller (MPPT logic) and a reference are fed to pitch control which is needed for phase 2 of the thesis for control and monitoring operation. Control and energy monitoring scheme for a stand-alone wind energy conversion system is shown in Figure 1.

A. Control of Standalone Wind Energy Conversion System

The modeling of wind turbine should create a model as simple as possible from a mechanical point of view. But capable of providing good description of the electrical characteristics of a wind turbine, rotational speed and torque becomes the controlled variables in wind energy conversion process. The block diagram for control of standalone wind energy conversion system is shown in Figure 2. In this work, the proposed wind energy conversion system is designed using aerodynamic model. The turbine speed as well as wind speed is linearly designed. These two are the inputs for the transmission system. The transmission system connected on the main turbine and rotor rotates the shaft which is connected to an electrical generator viz. a synchronous generator. The synchronous generator produces an uncontrolled AC output. The uncontrolled AC voltage is then rectified by using a rectifier. The rectified DC voltage is then controlled using a DC-DC buck converter by employing a PWM charge controller.

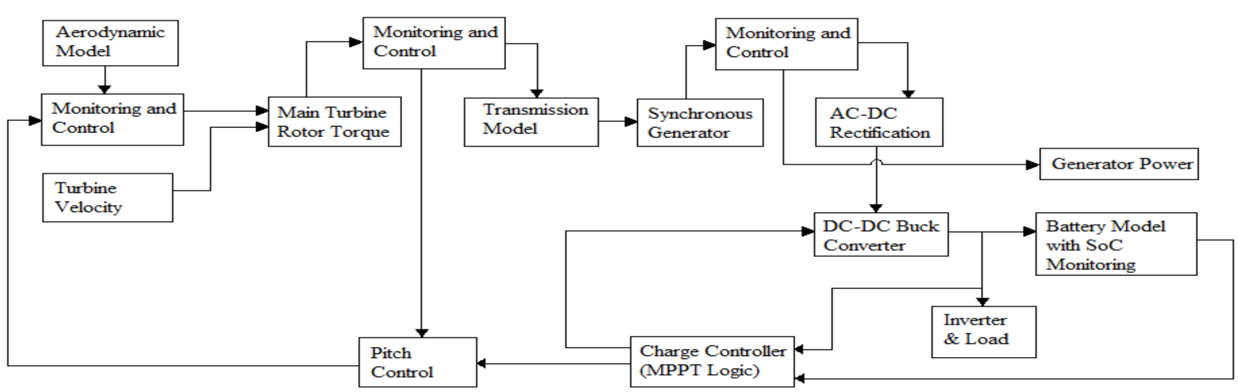

Figure 1 Control and Energy Monitoring Scheme for a Stand-Alone Wind Energy Conversion System

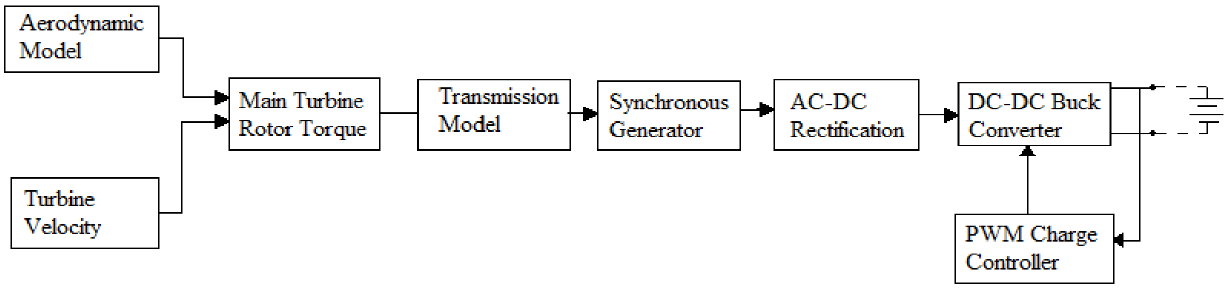

Figure 2. Control of Stand Alone Wind Energy Conversion System

IV. RESULTS AND DISCUSSIONS

An attempt is made to generate controlled DC output from a wind energy conversion system. From the preceding section, it has been observed that there is a need for suitable control and energy monitoring scheme for WECS connected to a stand-alone load.

The important achievements made in the work are highlighted as follows;

The rotor speed (ω_{rot}) of the wind turbine and aerodynamic torque (T_{rot}) are used to feed the transmission model. The transmission model provides the conversion of torque at output as mechanical torque. From the torque and mechanical power, the generator speed is fed to the synchronous generator system. The dynamic behavior and electrical properties of a wind turbine model are analyzed. The generated output voltage and frequency are shown in Figure 3.

- The input and output voltage have been figured out. The generator output has been directly connected to rectifier for the conversion AC-DC process. The input peak to peak voltage level has been identified from the graph. The output DC voltage is identified as a constant value. The rectified output voltage is shown in Fig.4. Control scheme has been developed for DC-DC buck type converter to make the switching device on and off. Start-up with the buck type DC-DC converter has been shown in Figure 5. From the Figure, it is found that DC-DC converter has a peak consumption of reactive power right after connection to the switching component and inductor. This has been identified with the help of measuring the input current value in DC-DC converter. When the control signal is applied to the converter, the output voltage gets the steady state. Steady state voltage is controlled by the reference voltage provided to the control circuitry. DC-DC buck converter used for battery charging is designed and analyzed.

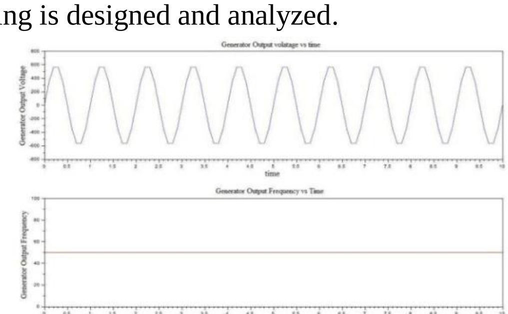

Figure 3. Generator output voltage and frequency.

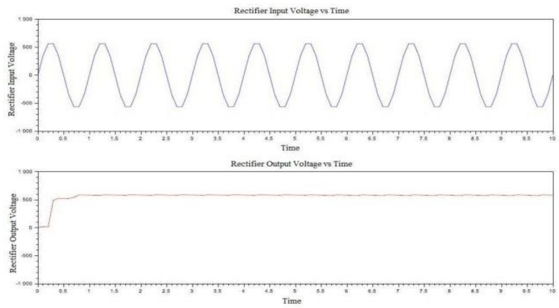

Figure 4. Rectifier - Input and Output Voltage

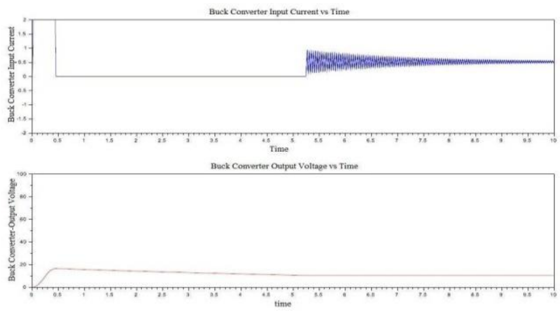

Figure 5. DC-DC Converter Buck Type

V. CONCLUSION

The power available from a WECS is very unreliable in nature. So, a WECS cannot ensure uninterrupted power flow to the load. In order to meet the load requirement at all instances, suitable storage device is needed. Therefore, in this thesis, a hybrid wind-battery system is chosen to supply the desired load power. To mitigate the random characteristics of wind flow, the WECS is interfaced with the load by suitable controllers.

Control scheme has been developed for DC-DC buck type converter to make the switching device on and off. The computer simulation in SCILAB-XCOS proves to be a valuable in predicting the system behaviour. The simulation result for proposed wind energy conversion process has been obtained. From the simulation result, it is observed that a controlled DC voltage could be generated in WECS by using a DC-DC buck converter and employing PWM control.

REFERENCES

[1]A. D. Sahin, “Progress and recent trends in wind energy,” *Progress in Energy Combustion Sci.*, vol. 30, no. 5, pp. 501–543, 2004.

[2] R. D. Richardson and G. M. Mcnerney, “Wind energy systems,” *Proc. IEEE*, vol. 81, no. 3, pp. 378–389, Mar. 1993.

[3] R. Saidur, M. R. Islam, N. A. Rahim, and K. H. Solangi, “A review on global wind energy policy,” *Renewable Sustainable Energy Rev.*, vol. 14, no. 7, pp. 1744–1762, Sep. 2010.

[4]M. T. Ameli, S. Moslehpur, and A. Mirzale, “Feasibility study for replacing asynchronous genrators with synchronous generators in wind farm power stations,” in *Proc. IAJC – IJME, Int. Conf. Eng. Technol.*, Music City Sheraton, Nashville, TN, US, ENT paper 129Nov. 17–19, 2008.

[5]G. K. Singh, "Self excited generator research—A survey," *Electric Power Syst. Res.*, vol. 69, no. 2/3, pp. 107–114, 2004.

[6]R. C. Bansal, "Three-phase self-excited induction generators: An overview," *IEEE Trans. Energy Convers.*, vol. 20, no. 2, pp. 292–299, Jun. 2005.

[7] S. C. Tripathy, M. Kalantar, and N. D. Rao, "Wind turbine driven self excited induction generator," *Energy Convers. Manag.*, vol. 34, no. 8, pp. 641–648, 1993.

[8] A. Chakraborty, "Advancements in power electronics and drives in interface with growing renewable energy resources," *Renewable SustainableEnergy Rev.*, vol. 15, no. 4, pp. 1816–1827, May 2011.

[9] F. D. Gonz´alez, A. Sumper, O. G. Bellmunt, and R. V. Robles, "A review of energy storage technologies for wind power applications," *RenewableSustainable Energy Rev.*, vol. 16, no. 4, pp. 2154–2171, May 2012.

[10] N. S. Hasan, M. Y. Hassan, M. S. Majid, and H. A. Rahman, "Review of storage schemes forwind energy systems," *Renewable Sustainable EnergyRev.*, vol. 21, pp. 237–247, May 2013.

[11] A. M. D. Broe, S. Drouilhet, and V. Gevorgian, "A peak power tracker for small wind turbines in battery charging applications," *IEEE Trans. EnergyConvers.*, vol. 14, no. 4, pp. 1630–1635, Dec. 1999.

[12] R. Kot, M. Rolak, and M. Malinowski, "Comparison of maximum peak power tracking algorithms for a small wind turbine," *Math.Comput.Simul.*, vol. 91, pp. 29–40, 2013.

[13] M. Narayana, G. A. Putrus, M. Jovanovic, P. S. Leung, and S. McDonald, "Generic maximum power point tracking controller for small-scale wind turbines," *Renewable Energy*, vol. 44, pp. 72–79, Aug. 2012.

[14] K. Y. Lo, Y. M. Chen, and Y. R. Chang, "MPPT battery charger for standalone wind power system," *IEEE Trans. Power Electron.*, vol. 26, no. 6, pp. 1631–1638, Jun. 2011.

[15] Muljadi E and Butterfield C P(1999), "Pitch-controlled variable-speed wind turbine generation" Industry Applications conference, 1999. 34th IAS Annual Meeting. Conf Record of the 1999 IEEE (Vol: 1)

[16]Raach, S (2014), "Nonlinear model predictive control of floating wind turbines with individual pitch control", American Control Conference (ACC), 2014.

[17]Malinga, B (2003), "Modeling and control of a wind turbine as a distributed resource" system Theory, 2003. Proceedings of the 35th Southeastern Symposium.

[18]Margaris and Hatziargyriou (2010), "Direct drive synchronous generator wind turbine models for power system studies", Power Generation, Transmission, Distribution and Energy Conversion (MedPower 2010), 7th Mediterranean Conference and Exhibition.

[19] Jie Chen and Dongxiang Jiang (2009), "Study on modeling and simulation of non-grid-connected wind turbine", World Non-Grid-Connected Wind Power and Energy Conference, 2009.WNWEC 2009.